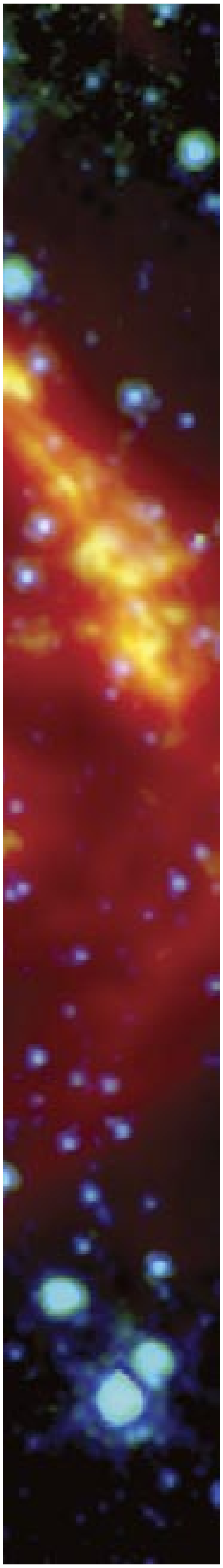

Astrophysics Branch

Overview

Scientists in the Astrophysics Branch pursue a wide range of laboratory and observational astronomy research. The Branch is particularly interested in studying the physical and chemical properties of astronomical phenomena by observing their radiation at infrared (and ultraviolet) wavelengths, beyond the range of visible light.

Planets, stars, and the interstellar medium of the Milky Way and other galaxies are rich in infrared spectral features which provide clues to their origins, physics, chemistry, and evolution. Researchers use state-of-the-art laboratories, ground-based, airborne, and space-based observatories to conduct their research. Astrophysics Branch scientists, engineers, and technicians also play key roles in developing new NASA space and airborne missions and instruments such as SIRTF, NGST, and SOFIA. The primary products of the Astrophysics Branch are new observations of the universe and new instrumentation developed to make these observations.

DOUG HUDGINS

Acting Chief, Astrophysics Branch

FITTING REFLECTION NEBULA SPECTRA WITH LABORATORY PAH DATA

Jesse Bregman and Pasquale Temi

The mid-infrared spectra of reflection nebulae are dominated by emission from polycyclic aromatic hydrocarbon (PAH) molecules. These molecules emit radiation in a number of discreet bands, and we can identify which molecules are present in reflection nebulae by matching the observed bands with those of specific PAH molecules measured in the laboratory. However, the astronomical spectra are not from a single PAH molecule, but rather a mixture of both electrically charged and neutral molecules. The charge state of the PAHs depends on the density of the nebular gas and the intensity of the incident ultraviolet (UV) radiation. Since the UV intensity decreases with increasing distance from the star that illuminates the nebulae, it is likely that the charge state of the PAHs changes from being more highly ionized near the star to more neutral at increasing distances from the star.

We have used spatial-spectral image cubes from the Infrared Space Observatory (ISO) to study how the spectrum of a reflection nebula changes with distance from its exciting star, and whether these changes can be explained by a change in the fractional ionization of PAHs. Our procedure is to first divide the nebula into regions that show similar spectra. For the reflection nebula vdB133, this procedure gave about 5 distinct regions, each with a somewhat different average spectrum. The main spectral difference between these regions was the relative strength of the emission bands in the 6-8 µm region relative to those in the 10-14 µm region. Each of the spectra were then fitted with a mixture of laboratory spectra of PAHs taken from the Ames Astrochemistry Spectral data base. Figure 1 shows the fit (dashed line and squares) to one of the spectral classes in vdB133 (solid line and triangles). A non-negative least squares fitting routine is used to fit the data with a linear combination of up to 36 laboratory spectra. In this example, the routine only used 15 of the spectra, weighting them so that when added together, they would provide the closest fit possible to the vdB133 spectrum.

Figure 2 shows the weights that the fitting routine calculated for three different spectral classes in vdB133. The points with class 5 spectra are closest to the star followed by class 2, while class 3 points are farthest

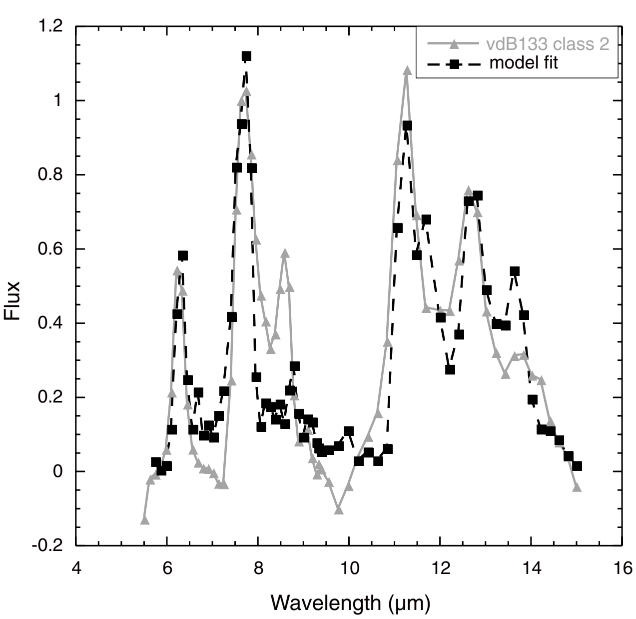

Figure 1. The average spectrum of one region in the reflection nebula vdB133 is shown as the solid line and triangles overlaid with a spectral fit (dashed line, squares) using a linear combination of spectra from the Ames Astrochemistry Lab data base.

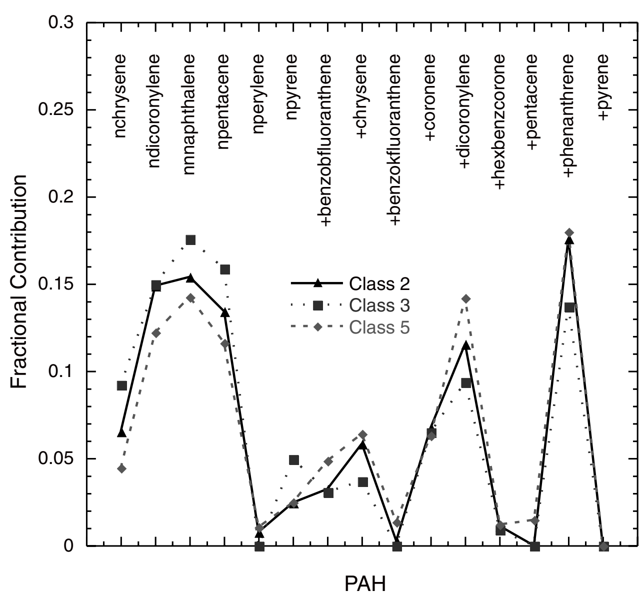

Figure 2. The contribution to the total intensity of the spectrum of 15 different neutral (designated n) and ionized (+) PAHs is shown for three different regions in vdB133. There is a progression of decreasing amounts of ionized PAHs relative to neutral PAHs as the UV radiation intensity experienced by the regions decreases.

from the star. The spectral fits show a progression of decreasing amounts of ionized species and greater amounts of neutral species progressing from class 5 to 2 to 3. Whether the individual PAHs that are used for the fit actually are present in the reflection nebulae is not known, although if the spectral changes can be explained by simply trading ionized for neutral species of the same molecule, then we might have evidence for that PAH being present. Further study using spectra of larger PAH molecules and only spectra of the same neutral and ionized species rather than the entire data base will perhaps lead to identification of individual PAHs.

ROTATION PROPERTIES OF SUN-LIKE PROTOSTARS

Thomas Greene

We can understand better how the Sun and Earth formed by studying very young stars in relatively nearby cosmic clouds of gas and dust where stars are forming now. Ames is involved in conducting astronomical observations of such young protostars using a powerful infrared spectrograph on the Keck Telescope in Hawaii. These observations reveal the physical properties of the youngest stars ever observed, and they show how these stars are interacting with the disks of material around them which will eventually form planets.

The temperatures, sizes, and rotation speeds of stars can be measured by observing them with spectrographs on large telescopes. Spectrographs disperse starlight into its constituent spectrum (colors), revealing telltale features which are produced by chemical elements in stellar atmospheres. Different features appear at different temperatures and pressures, and any rotation by the star broadens theses features via the Doppler effect. Putting this together allows precise measurement of stellar temperatures, sizes, and rotation speeds.

Until now it has been impossible to observe protostars – the youngest stars (less than 100,000 years old) which are still actively accreting their mass – with spectroscopy. This is because protostars form in very heavily obscured cosmic clouds of dust and gas where visible light cannot penetrate. However, protostars often emit large amounts of infrared radiation (wavelengths longer than visible light). Spectrographs which are sensitive to infrared light have recently been developed, and Ames personnel have been such instruments on the world's largest telescopes to measure the physical properties of protostars.

Early results from these studies indicate that protostars have temperatures and radii (sizes) which are very similar to somewhat older young stars (about 1,000,000 years old) which have stopped building up their masses. However, protostars are rotating about 2 –3 times as fast as the non-accreting young stars. This comes about for two reasons. First, a protostar is surrounded by a flattened disk of dust and gas which flow onto the central protostar, building up its mass. This material rotates faster and faster as it spirals through the disk, conserving its angular momentum just as an ice skater does when she brings in her arms and spins up. Therefore this accreting material spins up the protostar also. However (and secondly), the protostar is also coupled to its disk by strong magnetic fields which originate in the protostar (similar to the Sun in sunspot regions). This field couples the protostar to a region of its disk which is rotating rapidly. Older young stars (which are no longer accreting much matter) also have magnetic fields, but they are coupled to farther, more slowly rotating regions in their disks. The coupling distance and the resultant rotation speed are determined by the magnetic field strength and the amount of mass which is flowing from the disk onto the protostar. This is shown in Figure 1.

The rotation speeds of young stars and their disks are regulated by their magnetic strengths and the rate at which matter stops flowing onto the central stars. It is important to study this further because planets form in disks around stars, and the distribution of matter in disks is influenced by these processes.

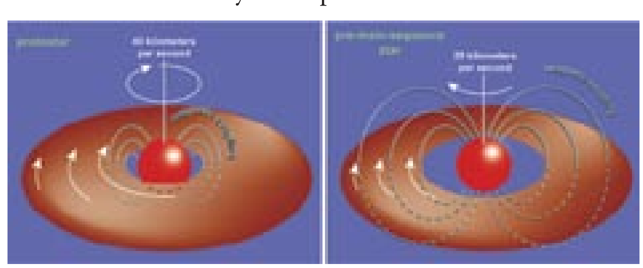

Figure 1. A schematic illustration which shows how stars are coupled to their disks for fast rotating protostars (left) and slower rotating young stars which have stopped accreting mass (right).

OPTICAL SPECTROSCOPY OF COSMIC / INTERSTELLAR ICES

Murthy Gudipati and Lou Allamandola

Water-rich ices, which harbor a wide variety of organic and inorganic species, are common throughout the Solar System and interstellar molecular clouds, the birthplace of stars and planets. The recent interest in searching for signs of life in water rich habitable bodies in the Solar System such as Europa and addressing questions concerning the abundance of water on Mars by the Mars Odyssey Mission exemplify the importance of water-rich ices in the cosmos. Chemical reactions induced within these cosmic ices by high-energy photons and cosmic rays play a vital role in the chemical evolution of these icy objects and their coloration. From the astrobiological perspective, complex prebiotic organic molecules are generated, including amino acids; amphiphillic, membrane forming molecules; and functionalized polycyclic aromatic hydrocarbons (PAHs).

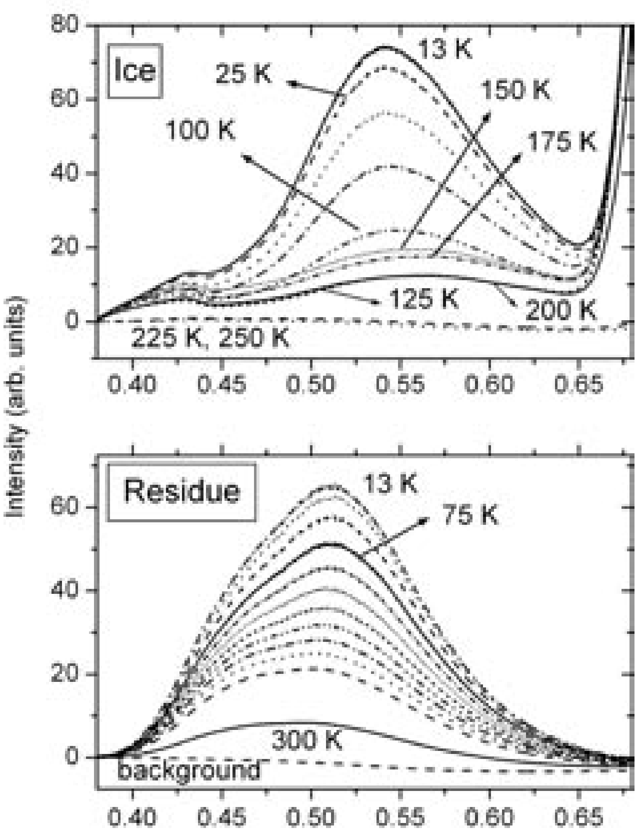

Figure 1: Temperature dependent luminescence from VUV-processed cosmic ice (top) and its residue (bottom) when excited with 380 nm light. The luminescence intensity increases with decreasing temperature.

Luminescence of cosmic ices: Due to the fact that cosmic ices are home to such important prebiotic chemistry, it is important to understand the primary physical and chemical processes that occur in these ices when they are exposed to high energy photons and cosmic rays. Our laboratory studies show that, upon vacuum ultraviolet (VUV) photolysis, transparent cosmic ice analogs containing H_2O, CH_3OH, CO, and NH_3 become strongly colored and exhibit green luminescence. This luminescence originates in the complex non-volatile organic molecules that are produced by the VUV photons and, upon warm-up to room temperature, remain even after the simple parent ice molecules have evaporated (shown in Figure 1). The ultraviolet-pumped green emission is an order of magnitude more intense at cryogenic temperatures (15 K) than at room temperature. Thus, very cold icy cosmic objects that receive considerable amount of high energy photons or cosmic rays should show this green emission. The types of objects which can exhibit this induced emission include comets, planets and their satellites, outer Solar System objects and interstellar ices. As an example, these studies have been used to reinterpret the reflection spectrum of the leading side of Iapetus, a moon of Saturn as follows.

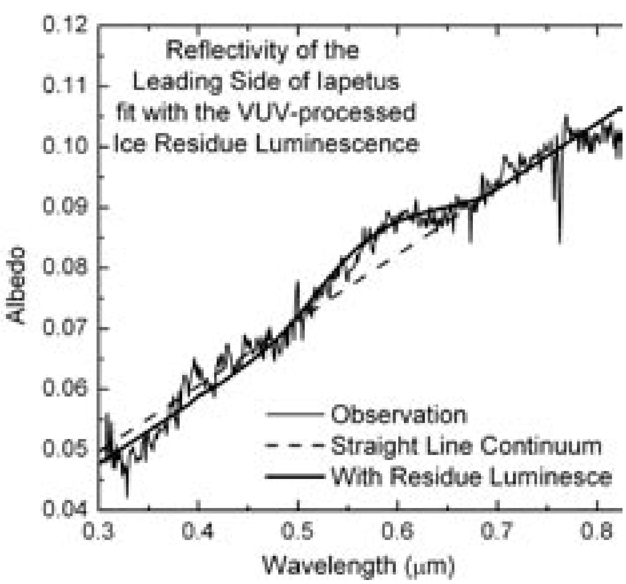

Figure 2: Reflection spectrum of the leading side of Iapetus (jagged solid line), fitted with a straight baseline (dashed line) to represent overall slope of the data. Addition of the ultraviolet pumped emission of the cosmic ice residue to the straight line results in a nice fit with the observed albedo (thick solid line).

It has been long known that Iapetus exhibits an extreme dichotomy in the amount of sunlight reflected from it's leading and trailing hemisphere. The dark, leading hemisphere, "reflects" less than 10% of the incident sunlight (albedo < 10%) while the bright, trailing hemisphere has an apparent enhanced "reflection" of ~50% (albedo ~50%). At visual and near-infrared wavelengths (~0.3–1.0 mm) the spectrum of the leading hemisphere is distinctly red with a weak and broad reflectance minimum near 0.67 mm. The broad feature centered near 0.6 mm might arise from luminescence of materials similar to the non-volatile residues mentioned above. Addition of the emission spectrum of cosmic ice residue, appropriately scaled, to the straight baseline representing the continuum color of Iapetus resulted in surprisingly good fit with the observed albedo, as shown in Figure 2.

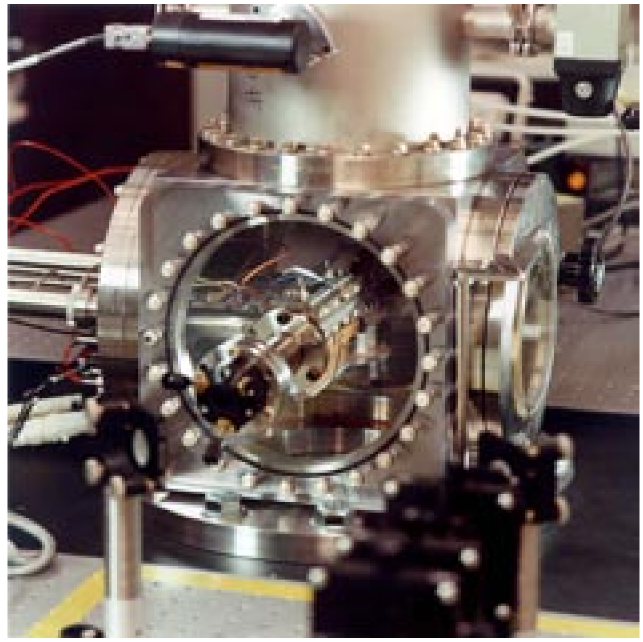

Figure 1: The figure shows Ames Interstellar Simulation Chamber (ISC). The physical conditions maintained inside the chamber approach interstellar conditions.

FROM GROUND TO SPACE - NEW RESULTS WITH AMES INTERSTELLAR SIMULATION CHAMBER: CAVITY RING DOWN SPECTROSCOPY OF INTERSTELLAR ANALOGS

Farid Salama, Ludovic Biennier, Jerome Remy, Robert Walker, Manish Gupta, and Anthony O'Keefe

New results have been obtained using Ames Interstellar Simulation Chamber (ISC) allowing for the first time to measure the spectral signature of large interstellar carbon molecules analogs and to accurately model the "cold" plasma that is generated in this unique astrophysical environment. The ISC facility has been developed to directly simulate gaseous molecules and ions at the low temperature and pressure conditions of interstellar space. This laboratory facility -that is unique within NASA- combines the techniques of Supersonic Free-Jet Expansion with the techniques of Cavity Ring Down Spectroscopy. The principle objective is to determine the spectroscopic properties of large interstellar aromatic molecules and ions under controlled conditions that precisely mimic interstellar conditions. The aim of this research is to provide quantitative information to analyze astronomical spectra in support of NASA's Space Science and Astrobiology missions, including data taken with the Hubble Space Telescope.

Understanding the origin, physical properties, and distribution of the most complex organic compounds in the universe is a central goal of Astrophysics and Astrobiology. To achieve this requires generating and maintaining large carbon-containing molecules and ions under interstellar-like conditions while simultaneously measuring their spectra under these conditions (i.e., in the gas phase at very low densities and at very low temperature). This has been accomplished by combining four advanced techniques: free supersonic jet expansion, low-temperature plasma formation and the ultrasensitive techniques of cavity ring down spectroscopy and multiplex integrated cavity output spectroscopy (ICOS). The ISC combines a pulsed-discharge, supersonic slit jet source mounted in a high-flow vacuum chamber with a ringdown cavity (see Figure 1). A beam of carrier gas (argon) seeded with polycyclic aromatic hydrocarbon molecules (PAHs) is expanded in the gas phase into the cavity ring down chamber. When the expanding beam is exposed to a high-voltage ionizing electronic discharge, a "cold" plasma is generated leading to the formation of positively charged ions that are characterized by very low, interstellar-like, rotational and vibrational temperatures (temperatures of the order of 10 and 100 K respectively are achieved this way). We have characterized the cold plasma as a restricted glow discharge. Recording the cavity ring down signal is a direct measurement of the absolute absorption by the seeding molecules and ions. Varying the gas pressure and the discharge voltage in the chamber also leads to the formation of nano-sized carbon particles and offers a highly sensitive way to trace the formation process of solid particles out of their molecular precursors (or "building blocks"). The results are illustrated in Figure 2 that shows the ICOS spectrum of the PAH acenaphthene ion (C12H10+). This unique experimental facility has been developed in collaboration with Los Gatos Research through a Small Business Innovative Research (SBIR) contract.

The data shown in Figure 2 can now be used to analyze the spectral signatures seen in astronomical spectra and to derive key information on the nature of the interstellar medium. For example, the absorption band of the PAH ion C12H10+ shown in Figure 2 can be directly compared to the absorption spectrum of the diffuse interstellar bands (DIBs). These bands that contribute to the global interstellar extinction were discovered eighty years ago and remain an enigma to this day.

For the first time, the absorption spectrum of large organic molecules and ions can be measured up to nanometer-sized species (nanoparticles) under conditions that mimic entirely the interstellar conditions.

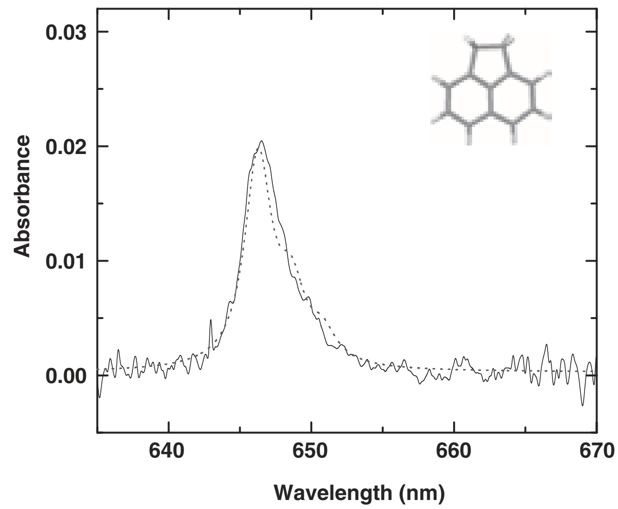

Figure 2: The multiplex ICOS absorption spectrum of the acenaphthene cation ($C_{12}H_{10}+$) measured for the first time in the gas phase under simulated interstellar space conditions. The spectrum is obtained when an argon free jet expansion seeded with acenaphthene is exposed to a high-voltage discharge.